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LR-80 FLIGHT TEST REPORT.(U)
SEP 80 J MAGUIRE, S J SOKOLOWSKI

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Technical Report -80-E-2

LR-80 FLIGHT TEST REPORT

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US ARMY AVIONICS R&D ACTIVITY

September 1980

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- Data Acquisition Unit (DAU)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

The report presents and analyzes the flight test results of the LR-80 attitude and Heading Reference System (AHRS) for the advanced attack helicopter (AAH).

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TABLE OF CONTENTS

APPENDICES

FIGURES

Page

TABLES

1. INTRODUCTION

The LR-80 is a Litton Guidance and Control System high performance Attitude and Heading Reference System (AHRS). This AHRS is planned to be used on the Army's Advanced Attack (AAH), NEAR TERM Scout and Cobra helicopters. Previously it had been planned for the Advanced Scout Helicopter (ASH).

Hughes Helicopter, prime contractor to the Army AAH program manager (PM) for the AAH, has subcontracted to Litton Systems for development and production of a high performance AHRS (LR-80). The Hughes/AAH development testing is not scheduled for completion until August 1981. As configured on the AAH, the LR-80 will provide attitude and heading to the AN/ASN-128 Lightweight Doppler Navigation System (LDNS) and to the fire control system.

The flight testing of the LR-80 was based on an unsolicited offer by Litton Guidance and Control Systems. In May 1979 they offered to lend a developmental model of the LR-80 for flight examination. As technical/developmental lead within AVRADCOM for position/navigation equipment and subsystems, AVRADA was in a unique position to obtain valuable flight test information for the PM's involved. With the PM AAH and PM ASH concurrence and funding, a limited test program was begun.

A limited program was planned to obtain preliminary information on the LR-80 performance as an AHRS and as part of the AHRS/doppler navigation system. A flight test program was initiated under the above guidelines to gain a quick assessment of the following parameters:

- Attitude and heading accuracy
- Navigation capability in conjunction with the ASN-128 Doppler
- Alignment Accuracy and Reaction Time
- Inflight alignment capability

The above listed items were investigated by flying an instrumented UH-1 helicopter over several flight profiles as follows:

- Straight and level
- Nap-of-the-Earth
- Special Dynamics
- High Dynamics

a. Flight Tests - Phase I. The flight tests were designed to exercise the LR-80 over each of the profiles listed above. Appendix A details the procedures and sequences of each of these profiles.

The first phase of flight tests was conducted from August to October 1979 at Lakehurst. During the course of these tests, a number of problems were encountered as follows:

- Inability to obtain consistent alignments with rotors turning.

- Introduction of heading error during pedal turns.

- Excessive amount of time to achieve alignment.

- LR-80 interface with AN/ASN-128.

- LR-80 shut down during transfer from ground-to-aircraft power.

- Excessive lag in the LTN-72 reference instrumentation (INS) heading signal during dynamic maneuvers.

- Random occurrence of erroneous LR-80 heading signals.

Since there was no benefit to continue testing under these circumstances, it was mutually agreed to allow Litton to take corrective actions for the above problems at their plant. After successful in-plant demonstration of the remedial measures, flight tests would resume.

b. Flight Tests - Phase II. Flight tests were resumed on 4 February 1980 and concluded on 12 February 1980. These tests were conducted with the LR-80 operating in the Doppler aided mode and consisted of the following:

7 each	Straight and Level
2 each	Straight and Level (Lakehurst to Picatinny)
1 each	Straight and Level (Picatinny to Lakehurst)
1 each	High Dynamics
1 each	Special Dynamics
1 each	Nap-of-the Earth (at Picatinny)

In addition to the above, two inflight alignments were performed and one of the flights to Picatinny was flown in the free inertial mode.

2. AIRCRAFT INSTRUMENTATION

Two methods of gathering information were employed in this program. To determine navigation accuracy, position data was obtained from the Doppler Computer Display Unit at each check point and compared to the known Universal Transverse Mercator (UTM) coordinates. To measure the attitude characteristics of the LR-80, a data recording system, consisting of a combination of Litton and Government furnished equipment, was installed in a UH-1H aircraft at Lakehurst Naval Air Station (NAS). A diagram of the instrumentation is shown in Figure 1.

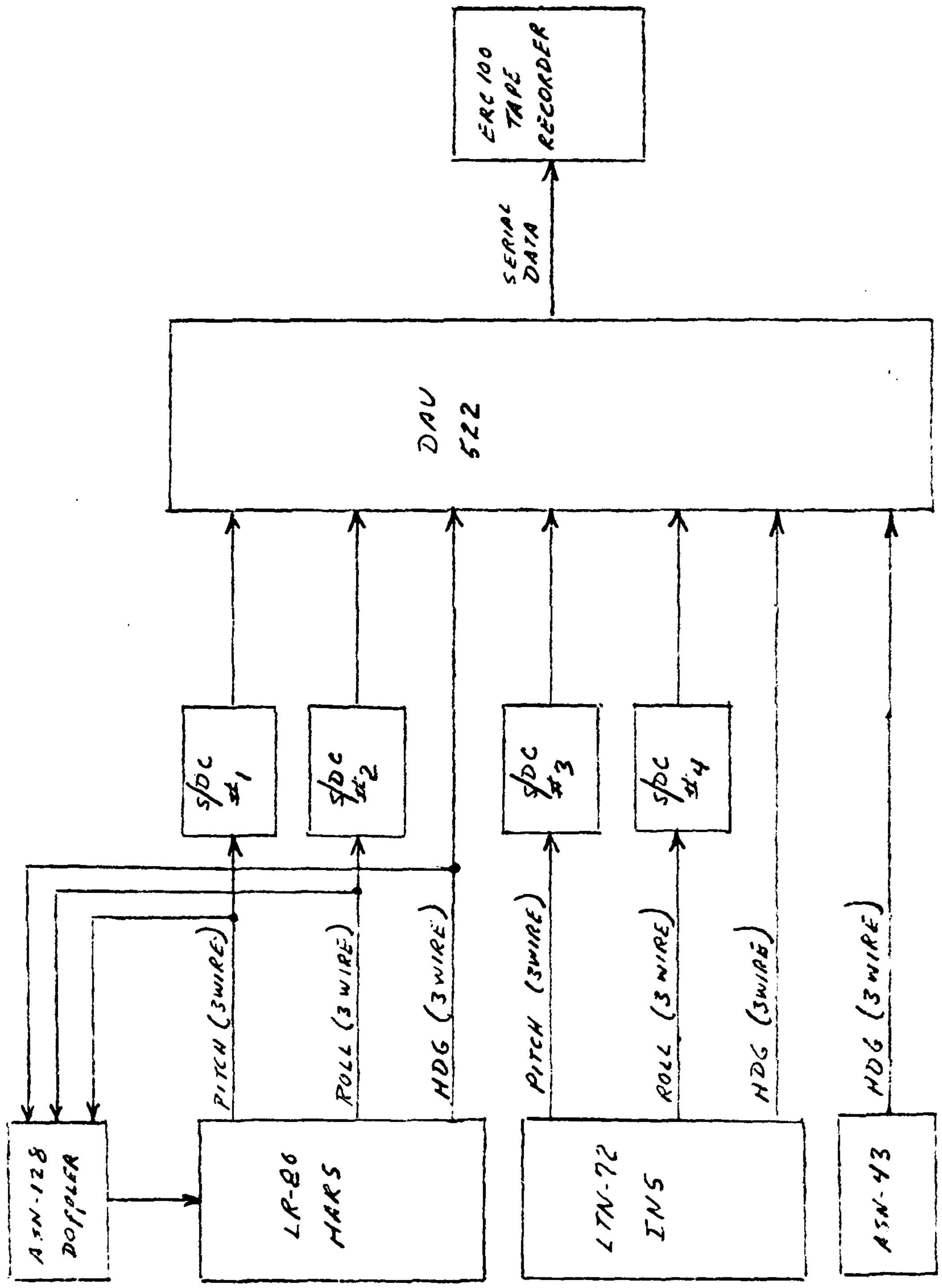


Figure 1. Instrumentation block diagram

The heading, pitch, and roll values from both the LR-80 and the LTN-72 INS were recorded on magnetic tape. The LTN-72 was used as the reference to determine deviation and tracking ability of the LR-80 parameters during subsequent data analysis. For comparison purposes, the heading from the standard aircraft ASN-43 was also recorded.

The three heading signals, each being a three-wire synchro signal, were connected directly to the Data Acquisition Unit (DAU) where internal synchro converters performed the necessary conversion. The three-wire pitch and roll signals were connected to external synchro-to-DC (S/DC) converters (supplied by Litton). The outputs of the S/DC's were then connected to analog channels in the DAU.

The DAU performed all the necessary conversions and multiplexing and generated a serial Pulse Coded Modulation (PCM) data stream for recording on the tape recorder (Genisco Model ERC-100). This recorder is a cartridge type which is capable of recording 2 hours of continuous data without changing tapes. Data was recorded at a rate of 10 samples per second.

3. FLIGHT TEST RESULTS

a. Alignment Accuracy. The LR-80 aligned to within 0.5° of the INS for all flights during this series of tests. Except for one straight and level flight and one inflight alignment, all alignments were begun from a cold start with outside ambient temperature ranging from -7°C to +1°C. In all cases, the aircraft rotors were turning prior to the start of alignment. Alignment times did not exceed 8.5 minutes with the majority being nearer an 8-minute duration. This was a major improvement over the Phase I tests where 10 to 12 minutes were often insuffcient to achieve an alignment of 0.5°. The individual alignment value for each flight is shown in the various tables throughout this report.

b. Navigation Accuracy. The navigation accuracy of the AN/ASN-128 (Lightweight Doppler Navigation System), using the LR-80's heading and attitude information as inputs, was evaluated. The AN/ASN-128 is the Army's doppler navigation system in which aircraft heading and attitude data are needed to transform the doppler velocities (V_x, V_y, V_z) into navigation velocities (V_N, V_E, V_Z).

The LR-80 provided the necessary aircraft heading and attitude information to the AN/ASN-128 in three-wire synchro format.

Position data was collected manually by recording the UTM position as displayed on the AN/ASN-128 when the aircraft overflew known checkpoints along the flight test course. The AN/ASN-128 position was initialized at the take-off point (Lakehurst NAS) and no further position updating was done. The flight test course was designed to divide the data into legs (distance between two checkpoints) which represented a data point. At each checkpoint position, data was collected and reduced to determine navigation accuracy. Each flight leg was analyzed to extract cross track (XTE), along track (ATE), radial position and accumulated radial position error in meters and percent of distance traveled. The cross-track angle error (in degrees) was also calculated for each leg. The definition of these errors is given in Appendix B.

The flight test course was set up using prominent landmarks that are easily identified from the air. The three major inaccuracies that occur due to the instrumentation are map errors, checkpoint fixing, and AN/ASN-128 resolution.

Map errors are a result of the inaccuracy of extracting checkpoint coordinates from the maps and the inaccuracy of the map itself. UTM coordinates for these points were taken from 1:24000, 7.5 minute Topographic maps. These maps were made by the Army Map Service and controlled by USGS, USC AND GS, USCE, and New Jersey Geodetic Survey. An estimate of these errors are in the order of 50 meters (radial) which would attribute an uncertainty in the position measurement of approximately 0.3 percent of distance traveled (using a 25.5 kilometer average distance between checkpoints).

The AN/ASN-128 UTM position display has a resolution of ten (10) meters in northing and easting. Therefore, position errors due to data entry and readout will be to the nearest five (5) meters in northing and easting resulting in a seven (7) meter resolution radially. The uncertainty in the position measurement due to the resolution of the AN/ASN-128 over an average leg would be approximately 0.048 percent of distance traveled.

Checkpoint fixing errors result from the collection of position data when the aircraft is not directly over the checkpoint. In an attempt to reduce fixing errors, the aircraft was flown over the checkpoints at a low airspeed and altitude. An estimate of the checkpoint fixing error is in the order of 10 meters radially which would attribute an uncertainty in the position measurement of approximately 0.055 percent of distance traveled.

Combining the three major position measurement errors in a Root Sum Square (RSS) manner, the uncertainty of the measurement system is in the order of 0.287 percent of distance traveled.

The data was reduced and presented in accordance with Air Standardization Agreement (Air STD 53/13A, 15 March 1979). "The Specification for Evaluation of the Accuracy of Airborne Doppler Navigation Systems." Circular Probable Error (CEP - 50-percent probable error) and 90-percent probable error are presented in Table 1 in terms of percent of distance traveled.

c. Heading and Attitude Accuracy. As mentioned previously, the heading, pitch, and roll signals from the LR-80 and LTN-72 were recorded. With the LTN-72 as the reference, the difference or delta (Δ) values for each of the parameters were calculated during the data analysis. For each leg or segment of the flight, the mean, standard deviation, and RMS of each Δ parameter were computed. In all cases, the delta is equal to the LR-80 parameter minus the LTN-72 value. The time increment between data values is 0.1 second (a data rate of 10 samples/sec). In addition, the Δ heading for the ASN-43 was also calculated for comparison purposes.

Curves have been plotted for a number of the flight maneuvers. For these, the delta heading is equal to the INS value minus the LR-80 value which gives opposite polarity than that of the statistical data. The delta pitches and delta rolls are calculated the same for the plots as they are for the statistical data.

TABLE 1. NAVIGATION ACCURACY (IN PERCENT OF DISTANCE TRAVELED)

FLIGHT TEST	# DATA POINTS	ALONG TRACK ERROR		CROSS TRACK ERROR		RADIAL POSITION				
		MEAN	ST DEV	MEAN	ST DEV	MEAN	GEOM MEAN	RMS	CEP	90% PROB
STRAIGHT & LEVEL	54	0.30	0.33	-0.43	0.48	0.73	0.70	0.79	0.73	1.08
HIGH DYN	4	0.24	0.27	-0.87	0.81	0.98	0.61	1.16	0.78	1.91
SPECIAL DYN	4	0.33	0.29	-0.51	0.30	0.65	0.56	0.70	0.61	1.03
TOTAL	62	0.30	0.32	-0.47	0.50	0.74	0.69	0.81	0.74	1.15

The accuracy of the data recording system is within the following values:

Headings $\pm$ 0.10°

Pitches and Rolls $\pm$ 0.20°

The LTN-72 specification requires that the system be checked in a static condition and meet the following requirements:

Heading	$\pm$ 0.2° at 0° heading $\pm$ 0.5° at 315° heading
Pitch/Roll	$\pm$ 0.2° at 0° roll/pitch $\pm$ 0.5° at 30° roll/pitch

These errors are primarily due to the way they are outputted from the LTN-72. The output synchro errors are the major cause of heading output inaccuracy. The pitch and roll inaccuracies are primarily due to digital to synchro converter errors.

(1) Straight and level flights. The straight and level flight course consisted of four legs as shown in Appendix A. All flights were flown over two laps except two flights which were one lap each. Alignments for all flights were from a cold start with the exception of Flight 2 which was a warm start.

Since there is no particular significance to any individual leg for the purposes of these statistics, the values for mean, standard deviation, and RMS are weighted results representing a composite of the entire flight. The accumulated statistics represent results for problem-free flights. A discussion of problems in the collection of data is given in a later paragraph of this report. The results for straight and level flights are shown in Tables 2 and 3.

TABLE 2. STRAIGHT AND LEVEL HEADING RESULTS

FLIGHT NO	NO. OF LEGS	NO. OF DATA POINTS	INIT ALIGN (DEG)	Δ HDG LR-80 (DEGREES)			Δ HDG ASN 43 (DEGREES)		
				MEAN	ST DEV	RMS	MEAN	ST DEV	RMS
1	4	21867	-0.45	-0.52	0.21	0.56	0.25	2.21	2.22
2	4	21650	-0.12	-0.42	0.23	0.48	0.34	2.01	2.04
4	8	44370	-0.35	-0.38	0.22	0.44	0.30	2.24	2.26
6	8	43837	-0.10	-0.25	0.20	0.32	0.11	2.36	2.36
7	8	46612	-0.27	-0.42	0.23	0.48	0.36	2.49	2.52
9	5*	24829	-0.40	-0.44	0.22	0.49	-0.44	1.89	1.94
TOTAL	37	203165	-0.28	-0.39	0.22	0.45	0.18	2.27	2.28

*Three legs were rejected due to erroneous data values.

TABLE 3. STRAIGHT AND LEVEL ATTITUDE RESULTS

FLIGHT NO	NO. OF LEGS	NO. OF DATA POINTS	INS PITCH RMS (DEG)	Δ PITCH LR-80 (DEGREES)			INS ROLL RMS (DEG)	Δ ROLL LR-80 (DEGREES)		
				MEAN	ST DEV	RMS		MEAN	ST DEV	RMS
1	4	21867	2.69	-0.02	0.14	0.14	2.11	-0.16	0.35	0.30
2	4	21650	2.04	-0.06	0.15	0.16	1.90	-0.12	0.22	0.25
4	8	44370	2.52	-0.06	0.17	0.18	1.92	-0.17	0.24	0.29
6	8	43837	2.62	-0.07	0.17	0.18	1.91	-0.14	0.23	0.27
7	8	46612	2.23	-0.11	0.18	0.21	2.00	-0.15	0.24	0.28
9	5*	24829	2.91	-0.10	0.16	0.19	2.44	-0.16	0.22	0.27
TOTAL	37	203165	2.50	-0.07	0.17	0.18	2.03	-0.15	0.24	0.28

*Three legs were rejected due to erroneous data values.

As seen in Table 2, the mean Δ HDG of the LR-80 did not deviate significantly from the initial alignment indicating relatively small drift in the system. The LR-80 heading tracked that of the LTN-72 quite well as shown by the low standard deviation value. The low values for each Δ HDG of the ASN-43 are due to the plus and minus results for each leg of the flight compensating each other. The tracking of the ASN-43 to the LTN-72 is relatively high as shown by the standard deviation normally exceeding 2 degrees.

In Table 3, the RMS values for the INS pitch and roll indicate the severity of maneuvers during the flight. For straight and level flights, these values are expectedly low. As can be seen from the table, the mean standard deviation and RMS results are all quite low with little variation from flight to flight. In fact, the results are within the measuring accuracy of the data acquisition system.

(2) High dynamic flight. The procedures employed for the high dynamic maneuvers are outlined in Appendix A. Due to an equipment failure toward the end of the flight to Atsion Dam (part 5 of the procedure), data could not be obtained for parts 6 and 7. This is explained further in a later paragraph ot the report. The overall results of the high dynamics are shown in Tables 4 and 5.

TABLE 4. HEADING RESULTS - HIGH DYNAMICS

FLIGHT 10

MANPOWER	NO. OF DATA POINTS	INIT ALIGN (DEG)	Δ HDG LR-80 (DEGREES)					Δ HDG ASN-43 (DEGREES)		
			MEAN	ST DEV	RMS	MAX POS	MAX NEG	MEAN	ST DEV	RMS
S&L	4890	-0.10	-0.05	0.20	0.20	0.70	-8.44	0.31	1.16	1.20
PEDAL TURNS	1537	--	-1.05	3.05	3.23	7.38	-8.61	4.94	42.30	42.59
CIRCLES	2647	--	-0.33	1.23	1.27	3.25	-3.25	1.11	5.91	6.01
COBRA TURNS	4541	--	-0.28	0.65	0.71	3.08	-3.60	-1.51	3.72	4.01
ROLLS THROUGHOUT LEG	11300	--	-0.39	0.74	0.83	2.99	-4.13	-2.42	4.45	5.07

TABLE 5. ATTITUDE RESULTS - HIGH DYNAMICS

FLIGHT 10

MANEUVER	NO. OF DATA POINTS	Δ PITCH LR-80 (DEGREES)			MAX PITCH (DEGREES)		Δ ROLL LR-80 (DEGREES)			MAX ROLL (DEGREES)	
		MEAN	ST DEV	RMS	UP	DOWN	MEAN	ST DEV	RMS	RIGHT	LEFT
S&L	4890	-0.07	0.18	0.20	11.88	3.06	-0.20	0.25	0.32	6.66	10.62
PEDAL TURNS	1537	-0.11	0.24	0.26	7.74	11.70	-0.13	0.30	0.33	8.46	12.42
CIRCLES	2647	-0.10	0.32	0.33	11.88	16.38	-0.20	0.36	0.41	57.60	59.58
COBRA TURNS	4541	-0.15	0.34	0.38	40.86	31.14	-0.17	0.33	0.37	47.88	45.00
ROLLS THROUGHOUT LEG	11300	-0.12	0.28	0.30	28.80	25.38	-0.15	0.43	0.46	72.36	71.28

(a) Pedal turns. Table 4 shows that the LR-80 Δ HDG reached a maximum of 7.38° for five left pedal turns and 8.61° for five right pedal turns. Upon completion of the left turns, the Δ HDG for the LR-80 settled out to -0.85°. At the conclusion of the right turns, the LR-80 returned to -0.21°. An examination of the data printouts indicates no significant lag in the recovery of the LR-80 heading to its settled-down value. Although rates and velocities were not directly recorded in this program, the data printouts indicate that the change in heading reached a rate of 70° per second. As can be seen in Table 4, the ASN-43 heading lags extremely far behind the LTN-72 heading under these high rate conditions. A plot of LR-80 delta heading versus time is shown in Figure 2. As mentioned before, the polarity is opposite to that shown in Table 4. Two consecutive data points (0.2 sec) are averaged for each point plotted on the graph.

The LR-80 pitch and roll signals (Table 5) track very well resulting in delta values only slightly higher than those obtained for straight and level flights.

(b) Circles. The circle maneuver subjected the LR-80 to large roll angles and heading rates. As shown in Table 5, rolls of almost 60° were achieved. The Δ roll variations are slightly higher than those of the straight and level flights but are still less than 0.5°. Plots of the results are shown in Figures 3 and 4. Again, two consecutive data points have been averaged for each point plotted on the graphs.

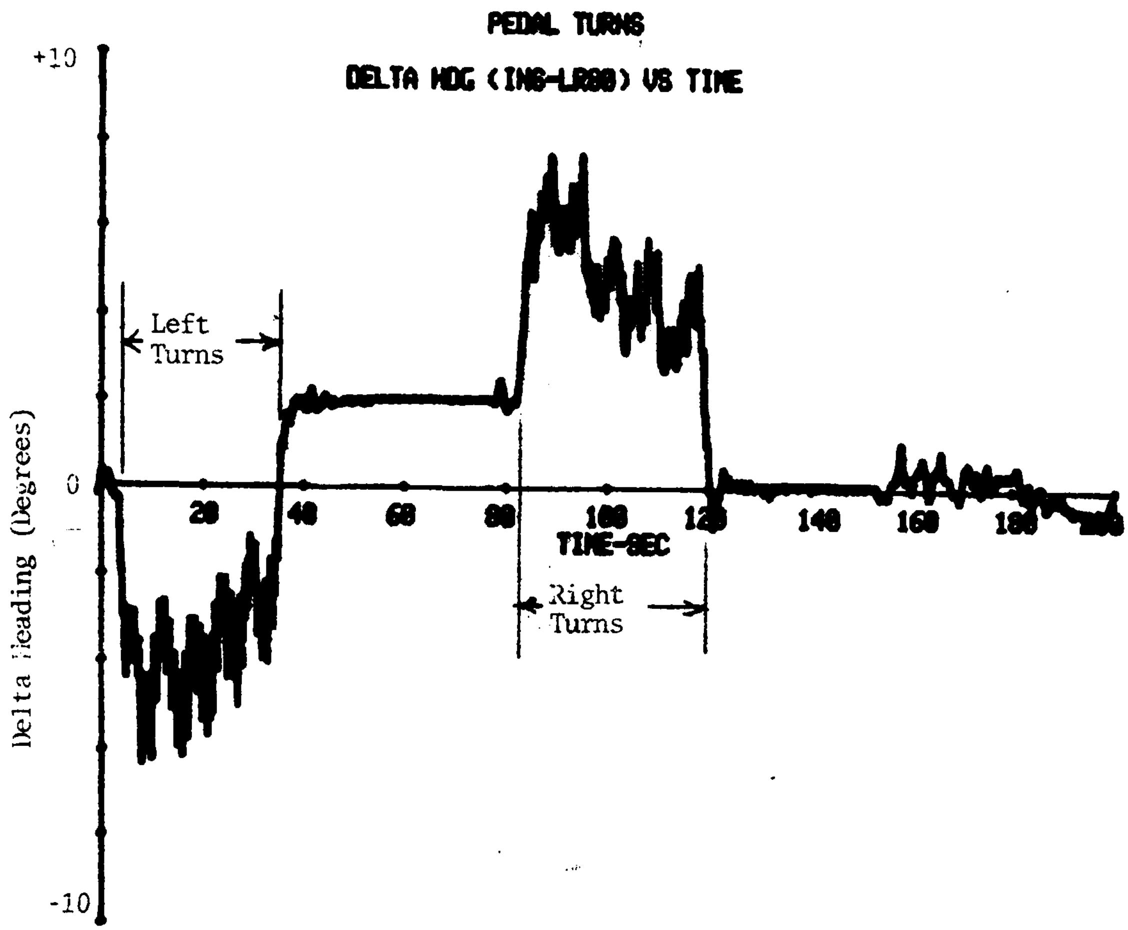


Figure 2. Pedal turns - Delta HDG (INS-LR80) versus time

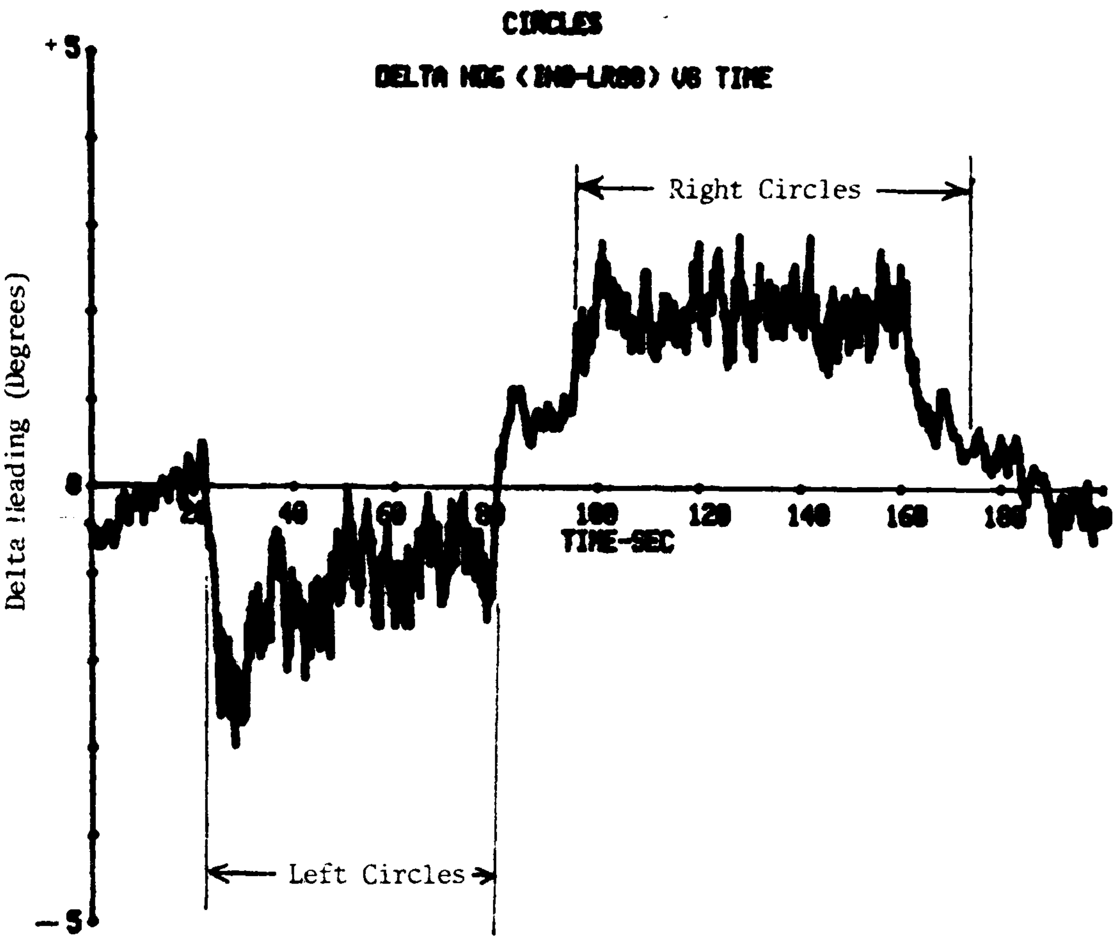


Figure 3. Circles - Delta HDG (INS-LR80) versus time

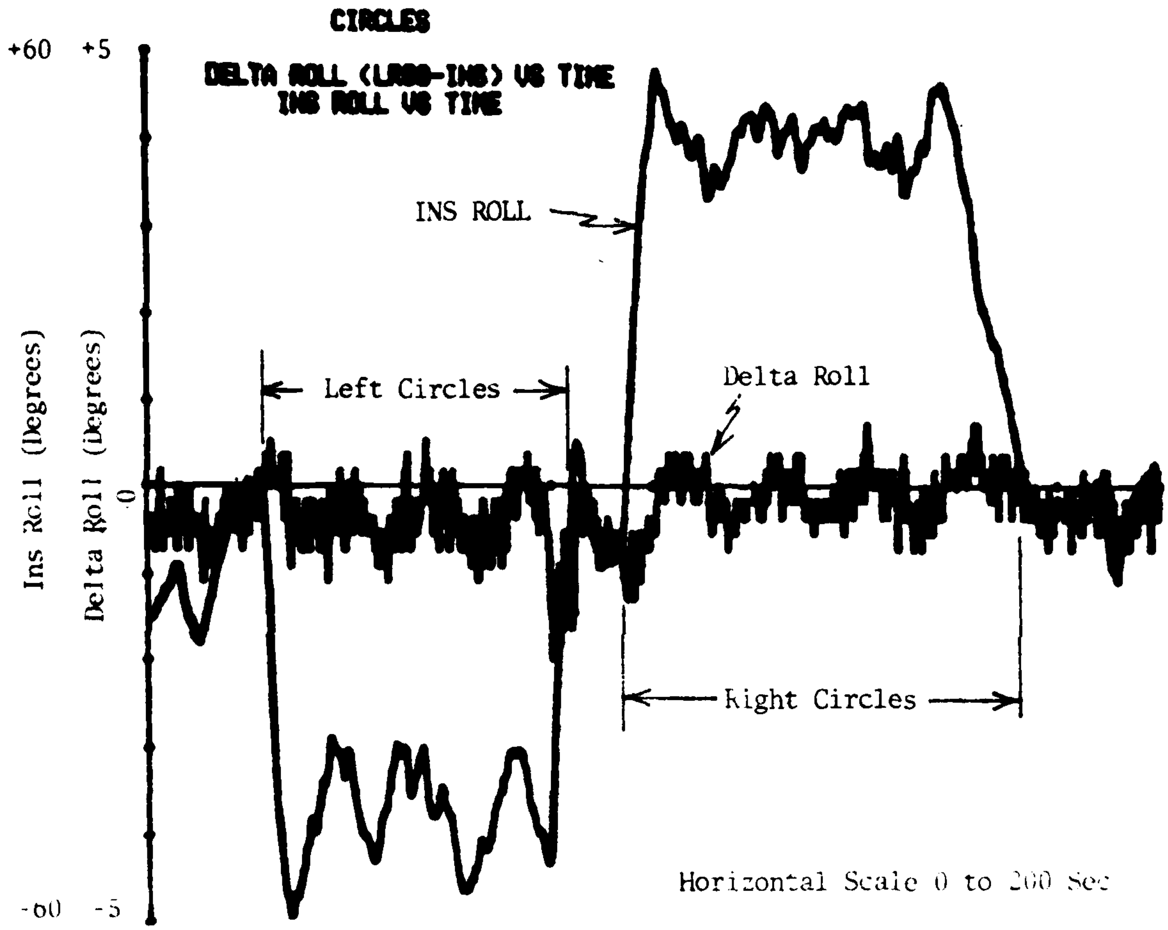


Figure 4. Circles - Delta roll (LR80-INS) versus time - INS roll versus time

The change in heading varied between 20° and 30° per second while the circles were in progress. Upon completion of the left circles, the Δ HDG for the LR-80 settled out to -1.1°. Upon completion of the right circles, the LR-80 had a Δ HDG of +0.43°.

(c) Cobra turns. Both large pitch and roll values were obtained during the Cobra turn maneuver as shown by the maximum values listed in Table 5. The LR-80 heading recovered to a delta value of -0.18° upon completion of the maneuver. Again the Δ pitch and Δ roll values are only slightly higher than those obtained in the straight and level flights. Plots of the pitch and roll variations are shown in Figures 5 and 6. Four consecutive data points (0.4 sec) are averaged for each point plotted on the graphs.

(d) Continual roll maneuvers. This maneuver consisted of flying a course leg from Coyle VOR to Atsion Dam while performing left and right rolls continually throughout the leg. Tables 4 and 5 list the results obtained during this profile. The main purpose of this maneuver is to determine its effect on navigation accuracy which was discussed in subparagraph 3b above.

(3) Special dynamics flight. The results of the special dynamics flight are shown in Tables 6 and 7. Refer to Appendix A for the procedures that were used.

TABLE 6. HEADING RESULTS - SPECIAL DYNAMICS

FLIGHT 8

MANEUVER	NO OF DATA POINTS	INIT ALIGN (DEG)	Δ HDG LR-80 (DEGREES)					Δ HDG ASN-43 (DEGREES)		
			MEAN	ST DEV	RMS	MAX POS	MAX NEG	MEAN	ST DEV	RMS
LEG 1-2 WEAVE	10084	-0.40	-0.48	0.36	0.59	0.62	-1.58	-1.83	1.66	2.47
PEDAL TURNS	5140	--	-0.61	0.72	0.95	2.29	-2.72	0.52	1.04	1.16
FIGURE 8	2120	--	-0.52	0.35	0.63	0.35	-1.32	-0.63	1.41	1.54
LEG 2-3 ACCEL/DECEL	7611	--	-0.43	0.15	0.45	0.53	-1.14	-1.19	2.27	2.56
LEG 3-2 ACCEL/DECEL	9719	--	-0.39	0.14	0.41	0.88	-1.23	0.77	2.38	2.50
RACE TRACK	12973	--	-0.39	0.14	0.41	0.53	-1.32	0.46	1.18	1.27
FLAT CIRCLE TURNS	4095	--	-0.32	0.29	0.44	0.88	-1.58	1.39	1.09	1.77
LEG 2-1 S&L	6902	--	-0.62	0.15	0.64	0.09	-1.23	1.81	0.90	2.02

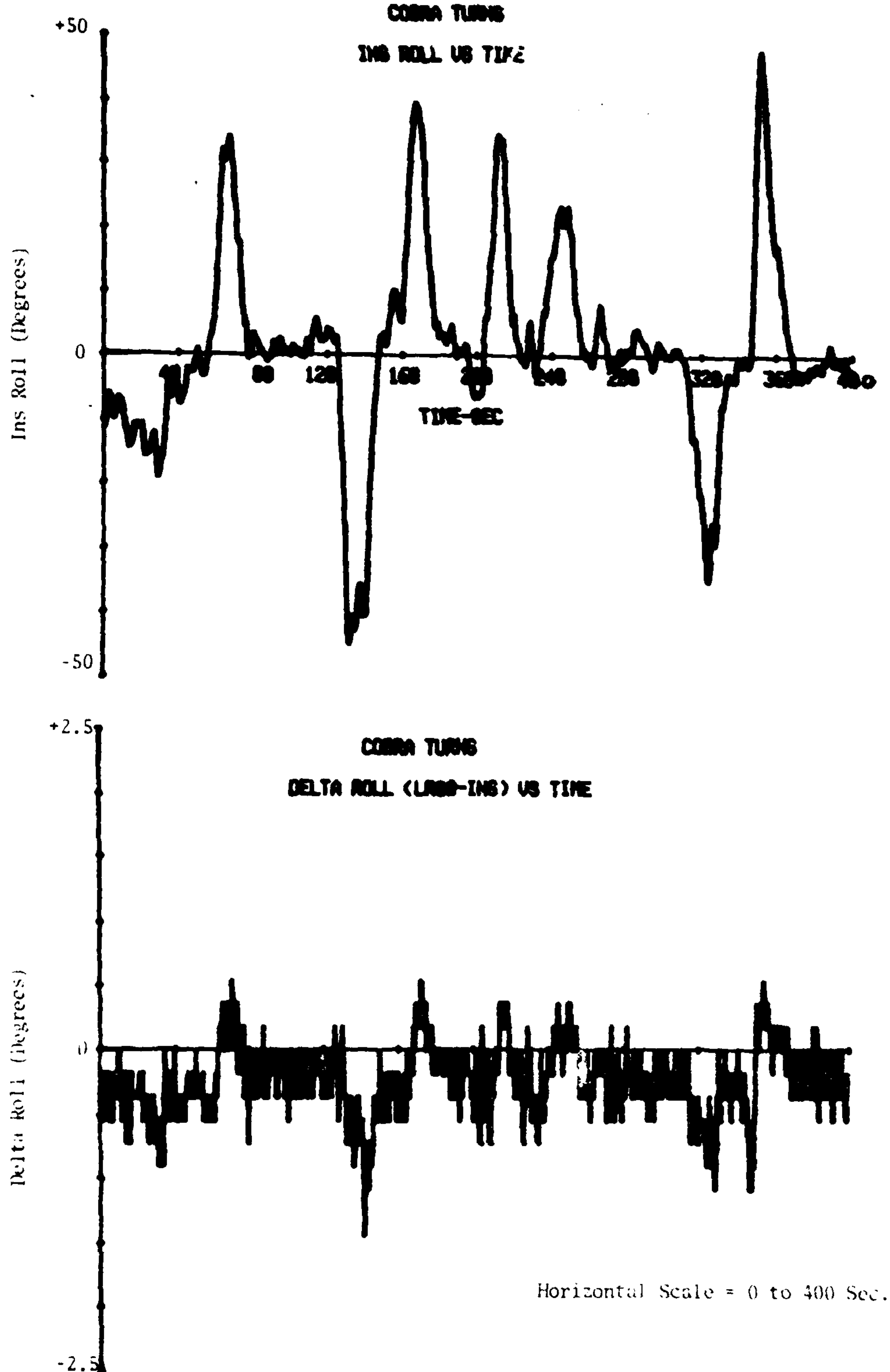


Figure 5. Cobra turns - INS roll versus time - Delta roll (LR80-INS) versus time

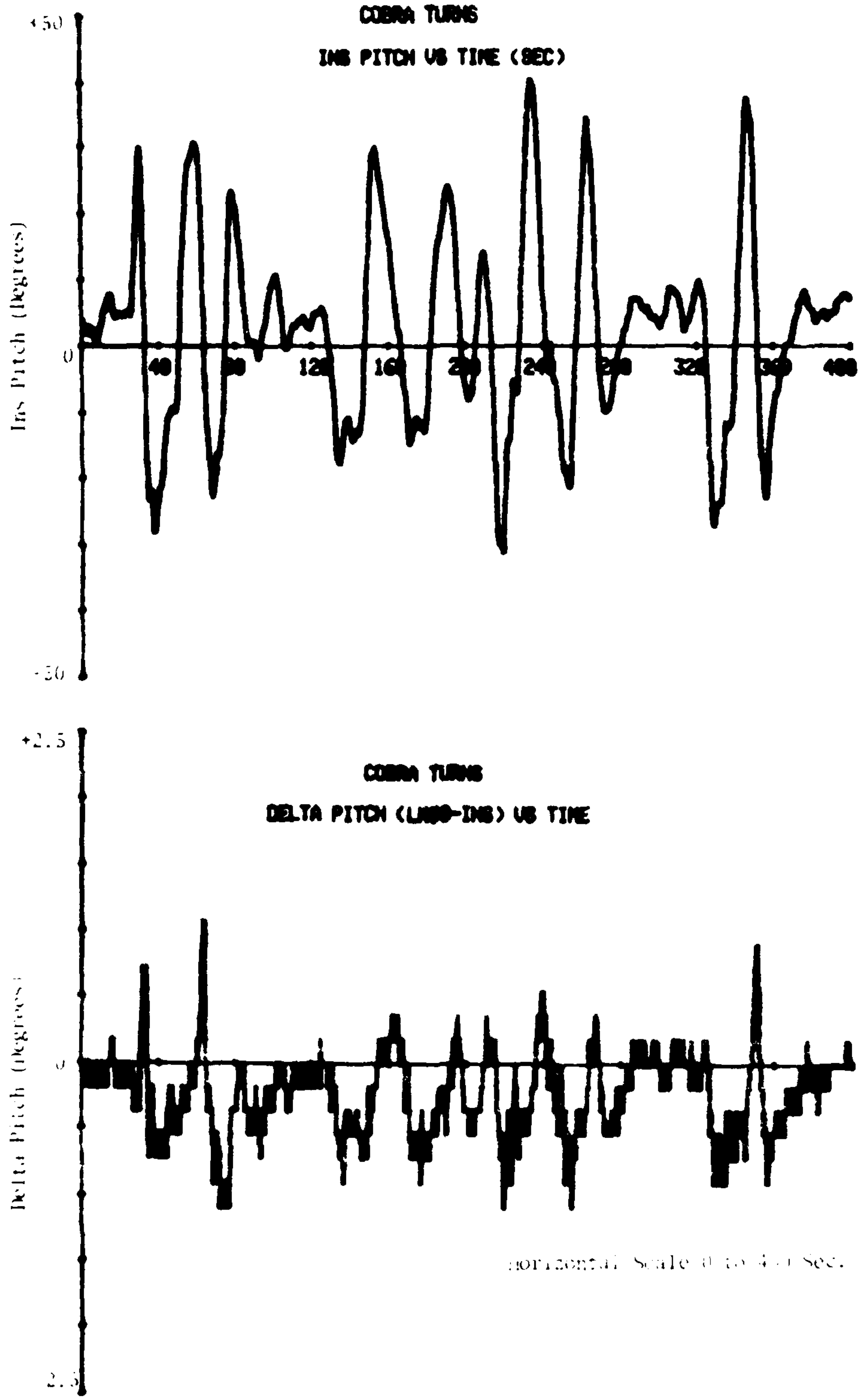


Figure 6. Cobra turns - INS pitch versus time (sec) - Delta pitch (LR80-INS) versus time

TABLE 7. ATTITUDE RESULTS - SPECIAL DYNAMICS

FLIGHT 8

MANEUVER	NO OF DATA POINTS	Δ PITCH LR-80 (DEGREES)			MAX PITCH (DEGREES)		Δ ROLL LR-80 (DEGREES)			MAX ROLL (DEGREES)	
		MEAN	ST DEV	RMS	UP	DOWN	MEAN	ST DEV	RMS	RIGHT	LEFT
LEG 1-2 WEAVE	10084	-0.11	0.15	0.19	8.10	7.38	-0.19	0.31	0.36	27.54	28.80
PEDAL TURNS	5140	-0.04	0.17	0.17	12.42	0.90	-0.18	0.25	0.30	6.12	[illegible]
FIGURE 8	2120	-0.07	0.18	0.19	8.64	4.68	-0.16	0.28	0.33	24.84	25.20
LEG 2-3 ACCEL/DECEL	7611	-0.10	0.18	0.21	12.24	4.86	-0.19	0.23	0.29	7.56	19.44
LEG 3-2 ACCEL/DECEL	9719	-0.09	0.18	0.20	13.14	12.60	-0.11	0.23	0.25	7.56	18.18
RACE TRACK	12973	-0.13	0.13	0.19	5.22	2.88	-0.18	0.23	0.29	2.88	27.36
FLAT CIRCLE TURNS	4095	-0.12	0.19	0.22	17.64	8.10	-0.17	0.24	0.30	18.90	14.22
LEG 2-1 S&L	6902	-0.08	0.15	0.17	7.92	4.68	-0.11	0.22	0.25	18.00	7.92

(a) Weave pattern. The weave pattern along the leg from Circle Hotel to Coyle VOR was done primarily to measure the effects on navigation accuracy which was discussed in subparagraph 3b above. A plot of the heading and roll variations is shown in Figure 7. Six consecutive data points (0.6 sec) were averaged for each point on the graph.

(b) Pedal turns. The pedal turns in the special dynamics were less severe than those performed during the high dynamics maneuvers. The rate of change of heading varies between 10 and 15 degrees per second throughout the maneuver. The LR-80 Δ HDG prior to the start of the left turns was -0.6°. Upon completion of the left turns, Δ HDG was -0.75°. Upon completion of the right turns, the Δ HDG had returned to -0.6°. The overall results are shown in Tables 6 and 7 and in Figure 8. Four consecutive data points were averaged for each point on the graph.

(c) Figure eight maneuver. The LR-80 Δ HDG changed from -0.6° at the start of the maneuver to -0.3° at the conclusion. Rolls up to 25° were encountered as shown in Table 7. Δ HDG's of slightly over -1.0° were experienced during right banks. The pitch and roll tracking remained good throughout the maneuver. A plot of the heading and roll variations are shown in Figure 9. Two consecutive points (0.2 sec) are averaged for each point plotted on the graph.

(d) Accelerate/decelerate maneuver. The accelerate/decelerate conditions that were done during 2 course legs produced no evident abnormal effects on the LR-80.

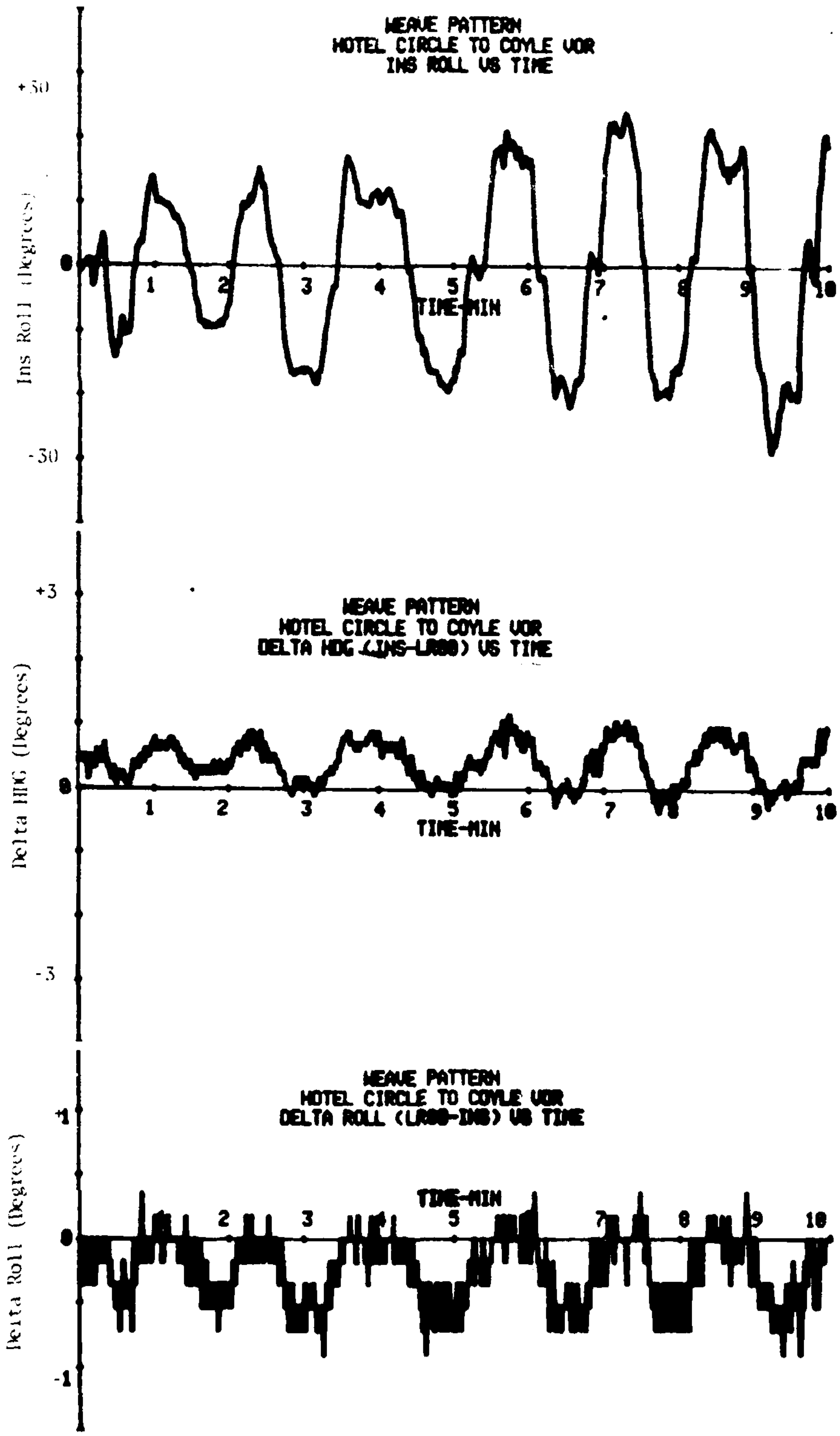


Figure 7. Weave pattern - Hotel Circle to Coyle VOR - INS roll versus time - Delta HDG (INS-LR80) versus time - Delta roll (LR80-INS) versus time

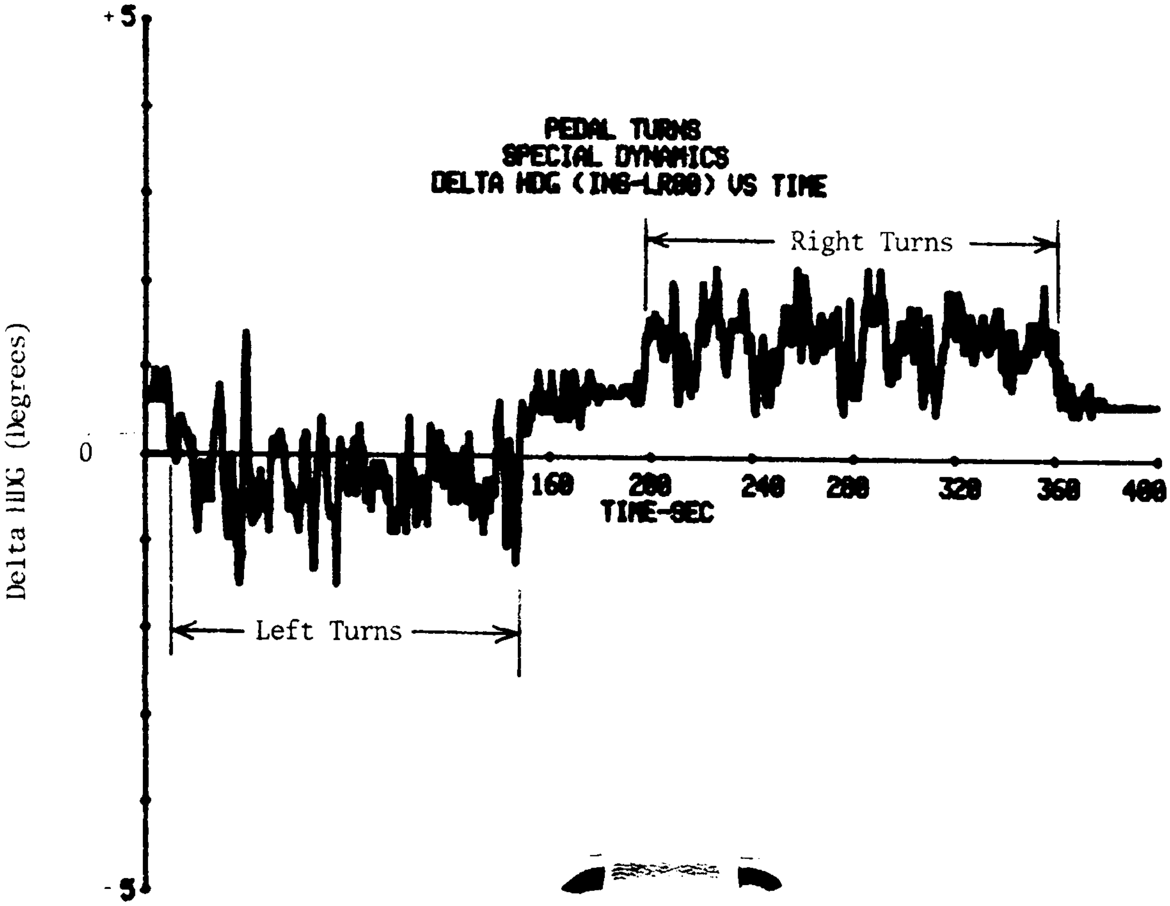
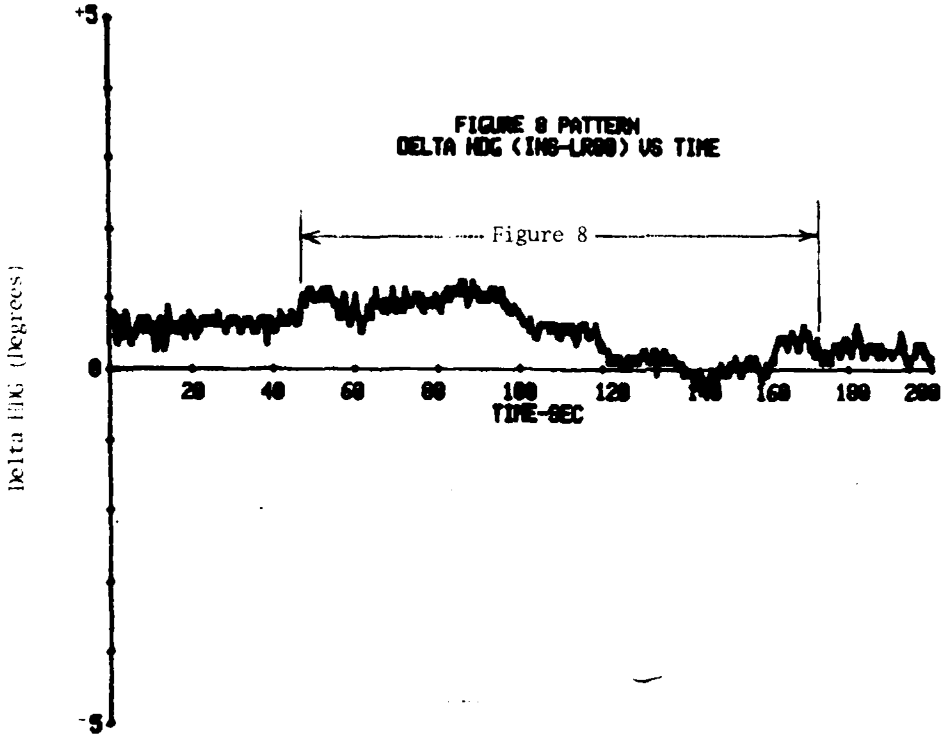


Figure 8. Pedal turns - Special dynamics - Delta HDG (INS-LR80) versus time



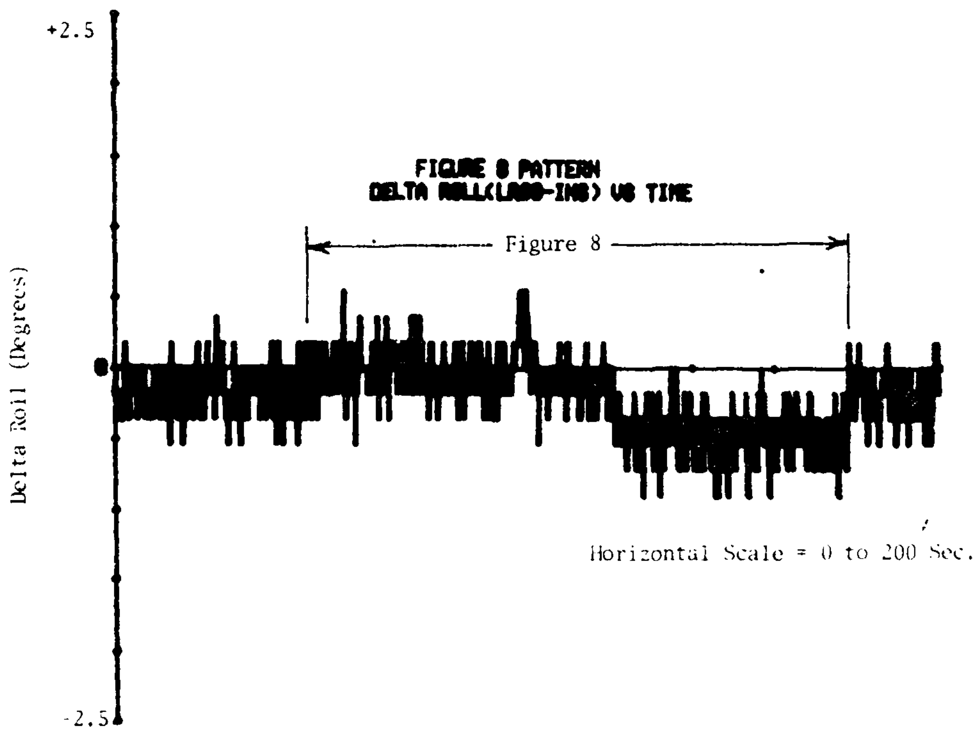


Figure 9. Figure 8 pattern - Delta HDG (INS-LR80) versus time - Delta roll (LR80-INS) versus time

1. Race track pattern. The race track pattern produced no evident abnormal effects on the LR-80 as indicated in Tables 6 and 7. A plot of Δ HDG for one complete pattern is shown in Figure 10. Seven consecutive data points (0.7 sec) are averaged for each point plotted on the graph.

2. Flat circle turns. The LR-80 Δ HDG began and ended at -0.6° for this maneuver. The standard deviation of the Δ HDG is slightly greater but overall results indicate no problems. Figure 11 shows a plot of Δ HDG for two turns. Two consecutive points (0.2 sec) are averaged for each point plotted on the graph.

(4) Nap-of-the-earth flight. The nap-of-the-earth (NOE) flight was flown out of the Picatinny Army Facility in Dover, NJ. The course is located in Stokes Forest and consists of four checkpoint positions. The flight consisted of 50-percent contour flying at 60 knots and 50-percent NOE at 10 to 30 knots. The data results for this flight are shown in Tables 8 and 9. The contour of the first leg of the course caused a predominantly left bank attitude for extended periods. This resulted in a somewhat higher LR-80 mean Δ HDG (0.51°) than for the other three legs which had banking in both directions. Table 8 shows greater variations (higher standard deviation) for the LR-80 Δ HDG for legs 2, 3, and 4. This is directly related to the magnitude of the maximum rolls which are shown in Table 9. The pitch variations are comparable to the results for straight and level flights, while the roll variations are only slightly higher.

d. Inflight Alignment. Inflight alignments were performed on Flights 5 and 15. In Flight 5, the alignment was from a warm start while Flight 15 was from a cold start. Table 10 shows the LR-80 Δ HDG response starting at the completion of the inflight alignment. The alignment times for the two flights were approximated from the data printouts which do not have an exact indication of start and stop times of the alignment. Plots of the two alignments are shown in Figures 12 and 13. Six consecutive data points (0.6 sec) have been averaged for each point plotted on the graphs.

The inflight alignment of Flight 5 appeared to take 7.3 minutes for an alignment accuracy of 0.25° (mean error over 9.7 minutes of flight after alignment). The inflight alignment of Flight 15 appeared to take 6 minutes for an alignment accuracy of 0.53° (mean error over 14 minutes of flight after alignment). Also after alignment, the heading appeared to drift at a continual 2°/hour rate of Flight 15.

The Δ pitch and Δ roll values (not shown) were comparable to the straight and level results.

e. Free Inertial. The free inertial flight, number 11, was flown on 7 February 1980 from Lakehurst, NAS, to Picatinny Arsenal. The flight profile was straight and level with approximate ground speed and heading of 90 knots north. The inital alignment was from a cold start and took 8.5 minutes to align within 0.2 degrees.

The results of this flight are shown in Table 11. Figure 14 shows a plot of Δ HDG versus time for the first 50 minutes of the flight. For each point in the figure, 3 seconds of data was averaged (30 data points).

TABLE 8. NOE HEADING RESULTS

FLIGHT 14

LEG	NO OF DATA POINTS	INIT ALIGN (DEG)	Δ HDG LR-80 (DEGREES)					Δ HDG ASN-43 (DEGREES)		
			MEAN	ST DEV	RMS	MAX POS	MAX NEG	MEAN	ST DEV	RMS
1	11549	0.0	0.51	0.31	0.60	3.87	-1.49	0.57	0.92	1.08
2	10293	--	0.22	0.48	0.53	2.99	-2.11	-0.32	1.52	1.55
3	8063	--	0.17	0.55	0.58	2.64	-2.02	0.58	1.78	1.87
4	8013	--	0.19	0.52	0.56	2.99	-8.70	-1.02	1.72	2.00
TOTAL	37918	--	0.29	0.49	0.57	--	--	-0.01	1.61	1.61

TABLE 9. NOE ATTITUDE RESULTS

FLIGHT 14

LEG	NO OF DATA POINTS	Δ PITCH LR-80 (DEGREES)			MAX PITCH (DEGREES)		Δ ROLL LR-80 (DEGREES)			MAX ROLL (DEGREES)	
		MEAN	ST DEV	RMS	UP	DOWN	MEAN	ST DEV	RMS	RIGHT	LEFT
1	11549	-0.10	0.19	0.22	7.20	5.58	-0.20	0.24	0.32	11.16	11.34
2	10293	-0.09	0.20	0.22	15.30	7.02	-0.21	0.33	0.39	27.72	28.62
3	8063	-0.12	0.22	0.25	10.08	12.06	-0.23	0.33	0.40	30.24	36.72
4	8013	-0.13	0.19	0.23	10.08	9.90	-0.23	0.32	0.39	26.82	36.54
TOTAL	37918	-0.11	0.20	0.23	--	--	-0.22	0.30	0.37	--	--

TABLE 10. INFLIGHT ALIGNMENT RESULTS

FLIGHT	NO OF DATA POINTS	TIME AFTER ALIGNMENT (MIN)	Δ HDG LR-80 (DEGREES)				
			MEAN	ST DEV	RMS	MAX	FINAL VALUE AT TOUCHDOWN
5	5820	0 to 9.7	0.25	0.87	0.91	5.19	-1.14
15	8400	0 to 14	-0.53	0.35	0.63	-1.40	--
15	8399	14 to 28	-1.12	0.50	1.23	-9.32	--
15	6276	28 to 42	-1.52	0.68	1.67	-9.23	--

FLIGHT 5 ALIGNMENT TIME = 7.3 MIN

FLIGHT 15 ALIGNMENT TIME = 6.0 MIN

TABLE 11. FREE INERTIAL RESULTS

	NUMBER OF DATA POINTS	MEAN ERROR (DEGREES)	STANDARD DEVIATION (DEGREES)	RMS (DEGREES)
HDG ASN-43	30,000	0.70	1.35	1.52
HDG LR-80	30,000	-0.54	0.16	0.57
PITCH LR-80	30,000	-0.11	0.19	0.22
ROLL LR-80	30,000	-0.17	0.22	0.28

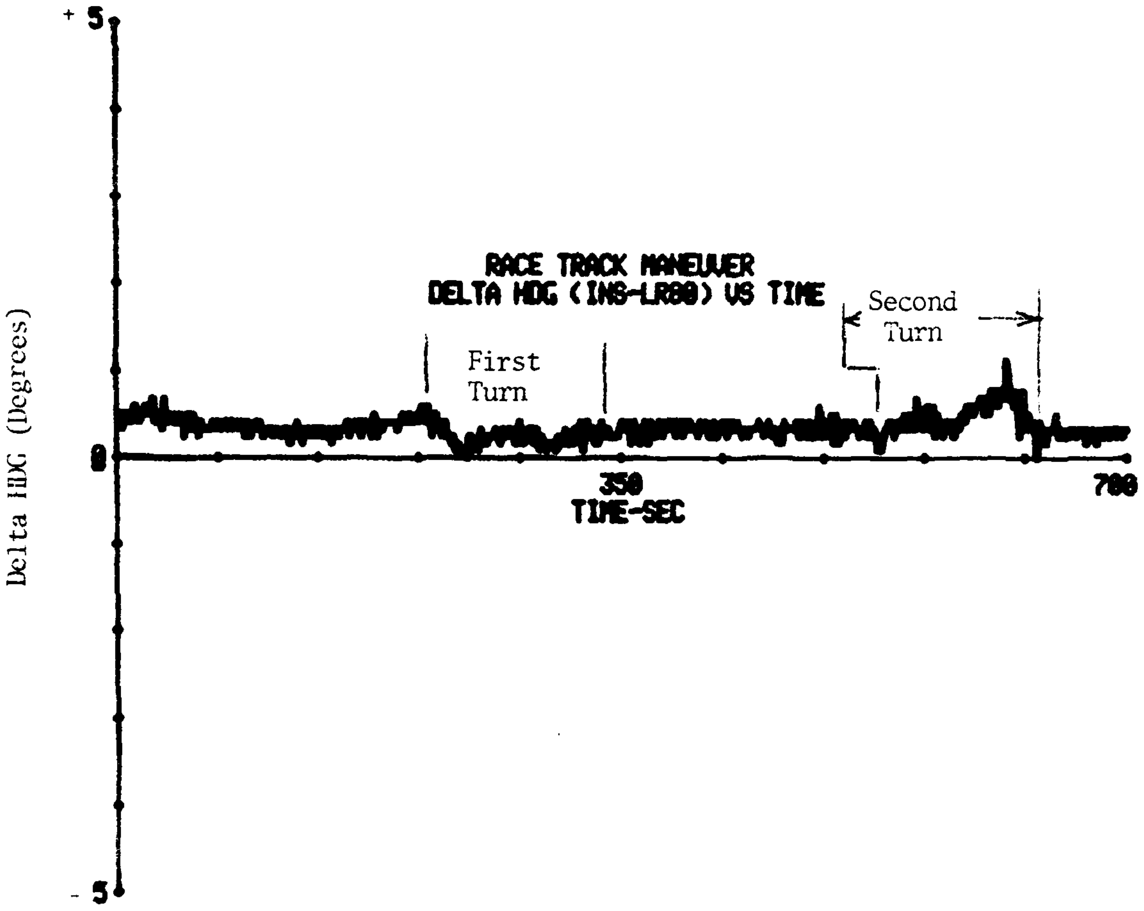


Figure 10. Race track maneuver - Delta HDG (INS-LR80) versus time

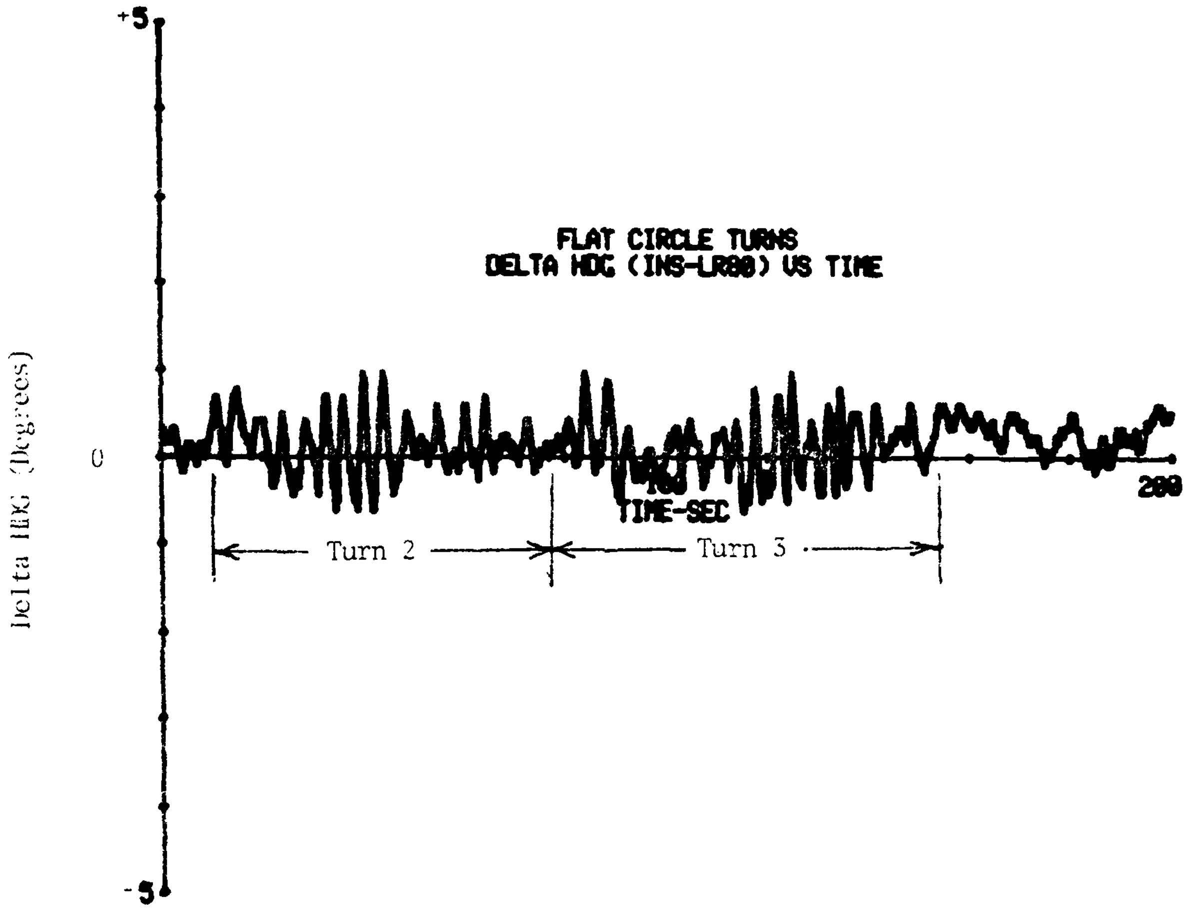


Figure 11. Flat circle turns - Delta HDG (INS-LR80) versus time

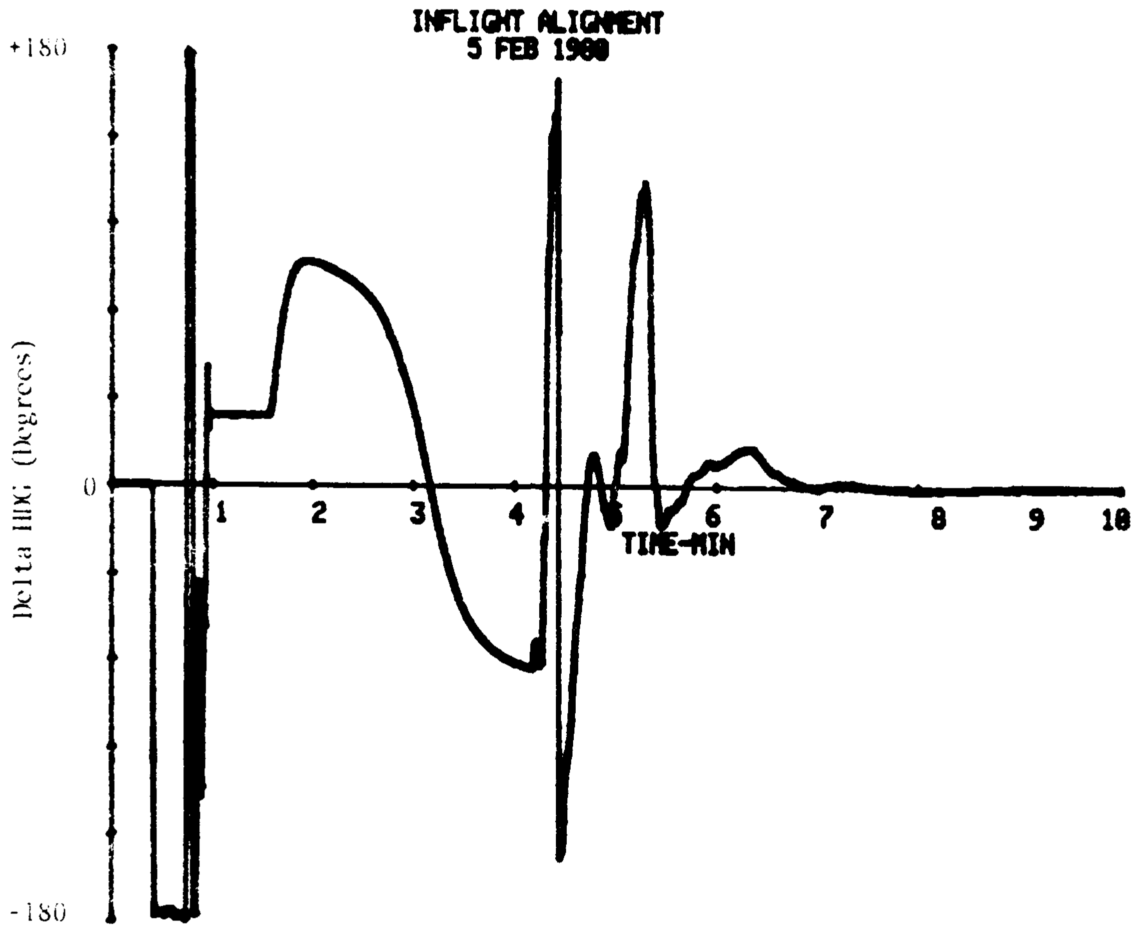


Figure 12. Inflight alignment - 5 Feb 1980

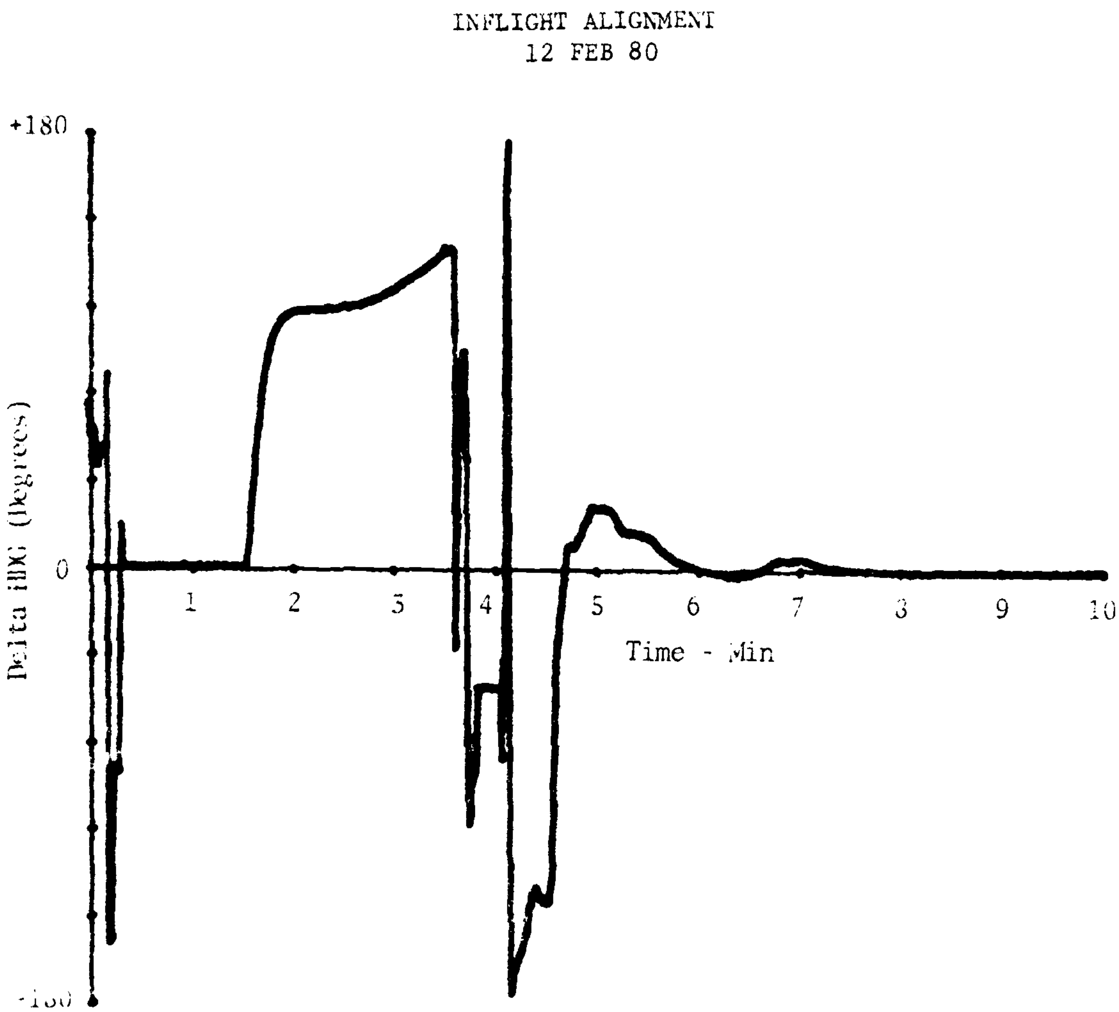


Figure 13. Inflight alignment - 12 Feb 1980

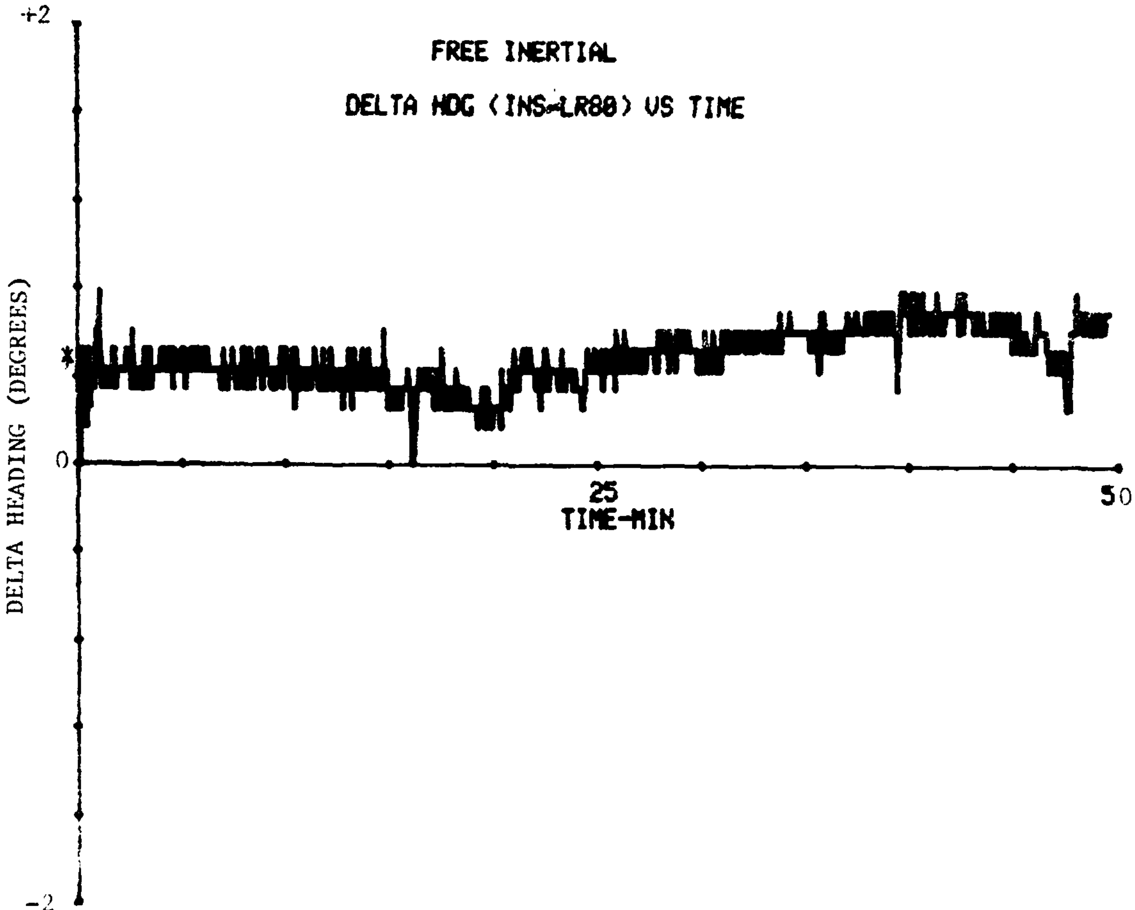


Figure 14. Free inertial - Delta heading versus time

f. Problem Flights.

(1) Flight 9 - straight and level course - 5 Feb 1980. On the fourth leg of this flight, the LTN-72 INS locked on a heading value of 74.88° for a 2-minute duration. The INS pitch and roll signals were erratic during this time period. The INS recovered after 2 minutes and the next two legs of the flight were error free.

On the last two legs of the flight, large errors in the LR-80 heading signal were randomly experienced. In the data reduction, a count is accumulated of the number of times the difference between the LR-80 and INS headings exceed 10°. These data points are rejected from any calculation. The number of rejections for these legs are as follows:

	Total No. of Data Points	No. of Points Rejected
Leg 7	5676	808
Leg 8	7205	566

The erroneous data was present for the last two thirds of leg 7 and continued for one-quarter of leg 8. At that point, there was no more occurrence of bad values for the remainder of the last leg. The LR-80 pitch and roll signals were normal throughout the entire flight.

(2) Flight 10 - high dynamics - 7 Feb 1980. Toward the end of the flight segment from Coyle VOR to Atsion Dam (continuous weaving), the LTN-72 INS again went into a locked condition. Valid data could not be obtained from this point on.

(3) Flight 11 - straight and level to Picatinny - 7 Feb 1980. The first two legs of this flight were error free. However, two-thirds of the way into the third leg, erratic LR-80 heading signals again occurred. They continued randomly until the early part of the fourth leg at which point they disappeared. The rejection rate is as follows:

	Total No. of Data Points	No. of Points Rejected
Leg 3	14379	150
Leg 4	4485	155

(4) Flight 12 - straight and level from Picatinny - 7 Feb 1980. Erroneous LR-80 heading signals occurred on the second leg of the return flight from Picatinny. This leg actually is a combination of legs 2 and 3 with continuous data from Sparta to Colts Neck. Erratic values first occurred three quarters of the way into the leg after a 40° left roll. They stopped a few seconds after the start of the next leg. The rejection rate is as follows:

	Total No. of Data Points	No. of Points Rejected
Combined Legs 2 and 3	27222	1898

(5) Flight 13 - straight and level to Picatinny - 12 Feb 1980. Erratic LR-80 heading signals were experienced on the third leg of this flight, starting approximately two-thirds into the leg. The signal became normal a few seconds into the fourth leg. The rejection rate is as follows:

	Total No. of Data Points	No. of Points Rejected
Leg 3	12981	1021
Leg 4	4094	23

(6) Flight 15 - straight and level from Picatinny - 12 Feb 1980. Erratic LR-80 heading signals were again experienced on the return flight from Picatinny after the NOE flight was conducted. Erroneous data first occurred 42 minutes after the flight began. The rejection rate for one segment of the flight is as follows:

Total No. of Data Points	No. of Points Rejected
8400	2124

g. Problem Discussion. The five occurrences of erratic LR-80 heading values outlined above are identical to one of the problems experienced in the Phase I testing discussed in paragraph 1a of this report. The problem did not occur at all during the first eight flights of this phase of the project. Due to its random and sporadic occurrence, it was not possible to ascertain the problem source.

Since the erratic data did not occur until the latter stages of the flight program, it was not within the scope of this project to perform a detailed investigation to determine if an equipment problem in the LR-80, the data acquisition system or an aircraft wiring problem of the three-wire synchro signal was the cause. However, its occurrence is noted as reference in the event any future testing is performed.

4. CONCLUSION

The purpose of this program was to determine the inflight performance of the LR-80 in flight profiles representative of typical Army helicopter missions. The LR-80 was evaluated in three areas during this test: reaction time/alignment accuracy, in-flight AHRS performance and navigation accuracy when operated with the AN/ASN-128 LDNS. The performance achieved is listed in Table 12 along with the requirements of the "Critical Item Development Specification for Heading Attitude Reference Set YAH-64" (AMC-DC-AAH-H1021 Code Ident. 02731) dated 13 March 1979.

TABLE 12. SUMMARY OF RESULTS

PARAMETER	OUTPUT TYPE	NORMAL ALIGN SPECIFICATION	NORMAL ALIGN TEST RESULTS	FAST REACTION TEST
Reaction/Alignment Time	N/A	5 Minutes	8.5 minutes	7 minutes
Initial Alignment Accuracy	Synchro	N/A	0.20° (Mean)	N/A
**Heading	Synchro	0.5° (1σ)	0.65° (RMS)	1.23° (RMS)
**Pitch	Synchro	0.5° (1σ)	0.20° (RMS)	--
**Roll	Synchro	0.5° (1σ)	0.31° (RMS)	--
Navigation Accuracy	ASN-128 Display	0.75% CEP*	0.74% CEP	--

*From Hughes Helicopter specification change #39 for the YAH-64 (improved navigation).

**The one sigma and RMS values are comparable numbers.

As can be seen from Table 12, the LR-80 met three (3) of the five (5) specified parameters tested: pitch, roll, and navigation accuracy. The two (2) parameters not met where: Reaction/alignment time and heading accuracy for normal alignment. However, the LR-80 did perform close to the heading specifications when the system is normally aligned.

It is important to note that the LR-80 did improve the AN/ASN-128 LDNS navigation accuracy to what was expected by Hughes Helicopter when the LR-80 was recommended to replace the AN/ASN-76 on YAH-64.

APPENDIX A. LR-80 FLIGHT TEST PROCEDURES

1. STRAIGHT AND LEVEL

a. The LR-80 will be aligned on the ground from a cold start with rotors turning. The value will be manually recorded.

b. Each flight will consist of two laps around the course depicted in Figure A-1.

c. Air speed will be maintained between 80 and 120 knots.

d. The Doppler will not be updated at the checkpoints.

e. The UTM coordinates from the Doppler CDU will be manually recorded at each checkpoint.

2. HIGH DYNAMICS

a. The LR-80 will be aligned on the ground from a cold start with rotors turning. The value will be manually recorded.

b. The Doppler will not be updated throughout the flight.

c. Fly straight and level from Circle Hotel to Coyle VOR. Manually record UTM coordinates at checkpoint.

d. At a safe altitude, do five complete rotations (pedal turns), first left and then right with a 30-second gap in between.

e. To effect a large roll and large heading rate, do five complete circles, first left and then right with a 30-second gap in between.

f. Do six 180° cobra turns.

g. Fly from Coyle VOR to Atsion Dam alternately rolling at maximum angles right and left continuously throughout the leg. Manually record UTM coordinates at checkpoint.

h. Fly from Atsion Dam to Coyle VOR alternately pitching at maximum angles up and down continuously, throughout the leg. Manually record UTM coordinates at checkpoint.

i. Fly straight and level from Coyle VOR to Circle Hotel. Manually record UTM coordinates at checkpoint.

3. SPECIAL DYNAMICS

a. The LR-80 will be aligned on the ground from a cold start with rotors turning. The value will be manually recorded.

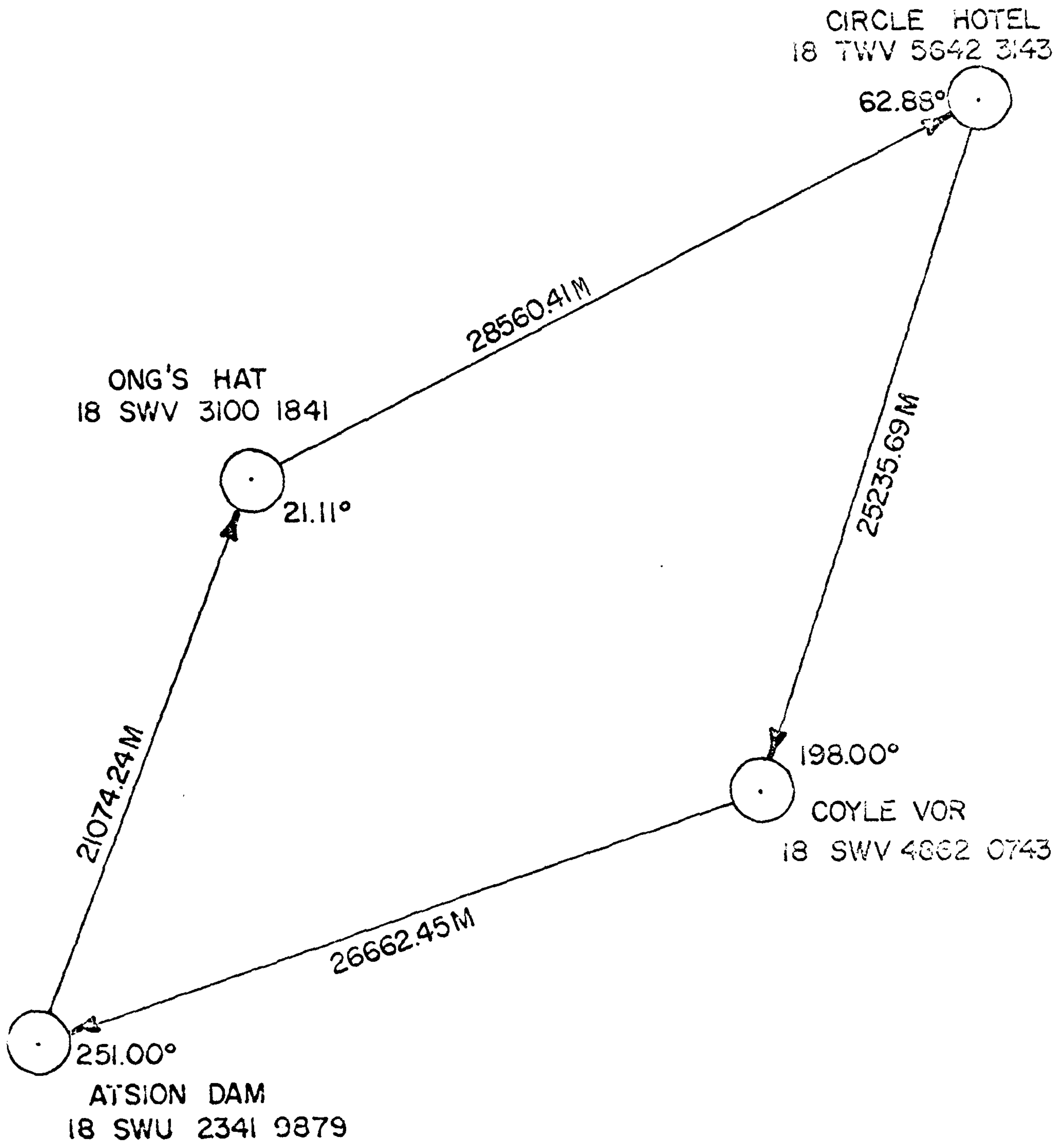
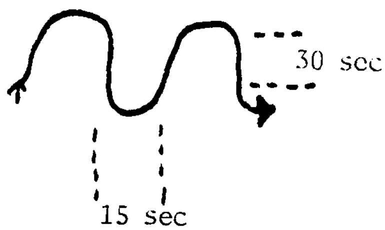


Figure A-1. Straight and level course

b. From Circle Hotel to Coyle VOR, perform coordinated turns throughout the leg at a ground velocity of 70 knots and a maximum bank of 45°. Manually record the UTM coordinates at the checkpoint.

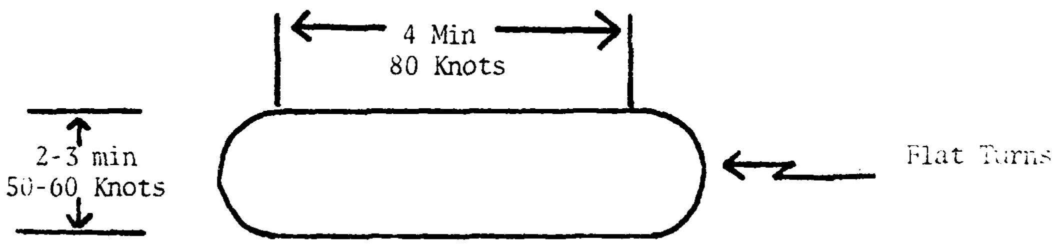


c. Do 720° flat pedal turns, first left and then right. The 720° turns should take between 30 to 40 seconds to complete.

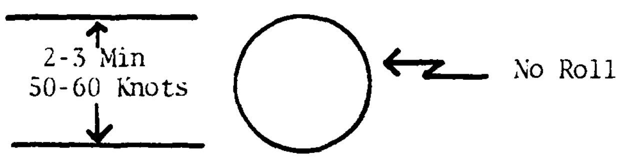
d. Do a complete figure 8 at a speed of 70 knots and a maximum bank of 45°.

e. From Coyle VOR to Atsion Dam, alternately accelerate from 0 to 100 knots and decelerate 100 to 0 knots throughout the leg. One complete cycle (0 - 100 - 0) should take 1.5 minutes total. Manually record the UTM coordinates at the checkpoint.

f. From Atsion Dam to Coyle VOR, alternately accelerate from 0 to 100 knots and decelerate from 100 to 0 knots throughout the leg. One complete cycle (0 - 100 - 0) should take 4 minutes total. Manually record the UTM coordinates as follows:



g. Do three complete circles as follows:



h. Fly straight and level from Coyle VOR to Circle Hotel. Manually record UTM coordinates at checkpoint.

APPENDIX B. ERROR DEFINITION

Each flight leg was analyzed to extract true ground track angle, leg distance, accumulated distance flown, cross-track angle error and position errors. The position analysis consisted of extracting (for each checkpoint) cross track, along track, radial position, and total flight radial position error in both meters and percent of distance traveled.

The definition of each parameter is described as follows (See Figure B-1):

A - leg initial checkpoint position.

B - leg ending checkpoint position.

C - AN/ASN-128's displayed position when the aircraft is over the leg's initial checkpoint position (A).

D - AN/ASN-128's displayed position when the aircraft is over the leg's ending checkpoint position (B).

GT - "true ground track angle" in degrees.

$$GT = \begin{cases} 90° - \tan^{-1}\left(\frac{\Delta N}{\Delta E}\right) & \text{for } \Delta E \geq 0 \\ 270° - \tan^{-1}\left(\frac{\Delta N}{\Delta E}\right) & \text{for } \Delta E < 0 \end{cases}$$

where $\Delta N = B_N - A_N$

$\Delta E = B_E - A_E$

A_N - UTM northing at the leg's initial checkpoint (A).

A_E - UTM easting at the leg's initial checkpoint (A).

B_N - UTM northing at the leg's ending checkpoint (B).

B_E - UTM easting at the leg's ending checkpoint (B).

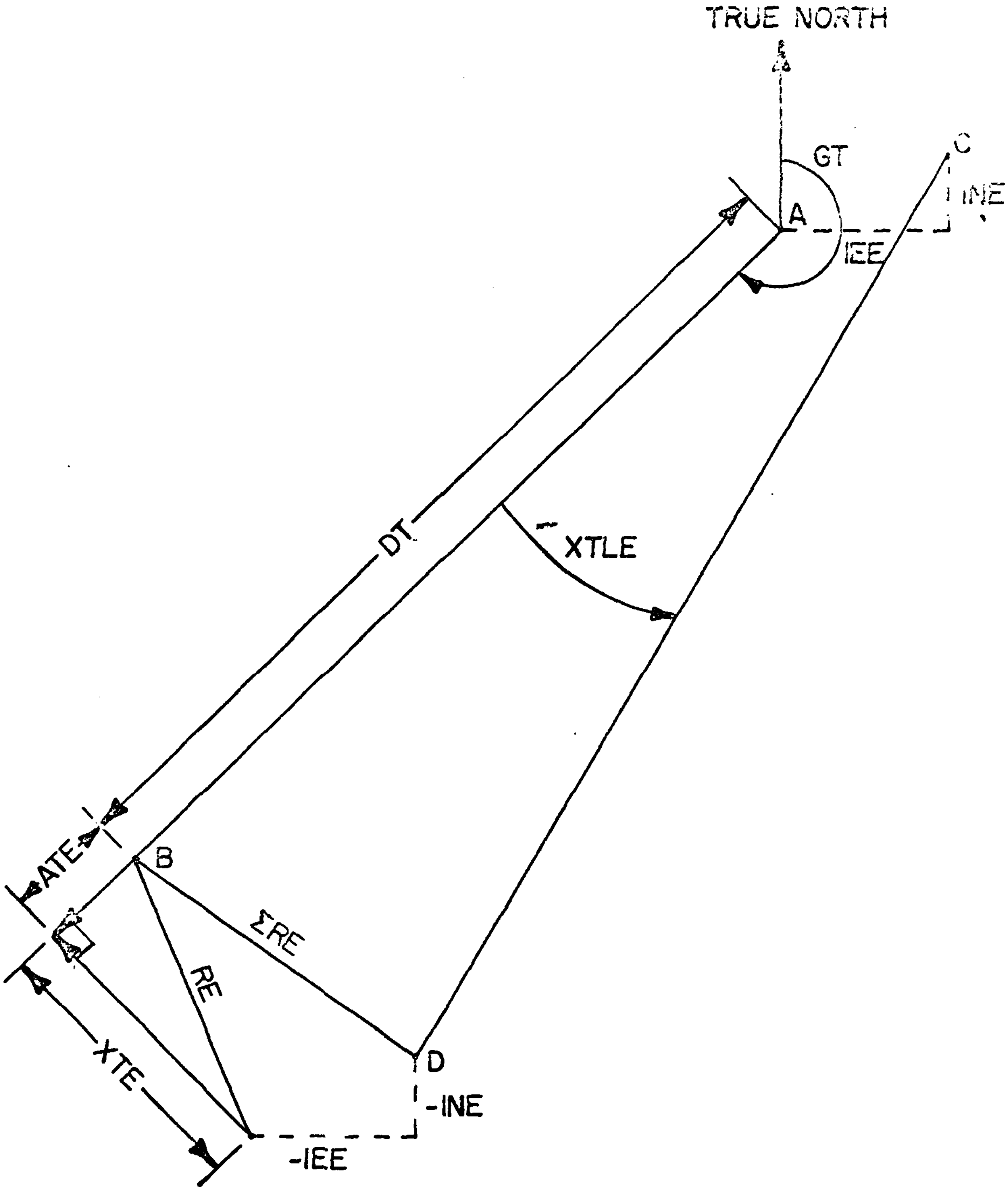


Figure B-1. Flight analysis

DT - "leg's distance" in meters.

$$DT = (\Delta N^2 + \Delta E^2)^{-1/2}$$

$XT\angle E$ - "cross track angle error" in degrees.

$$XT\angle E = \theta - GT$$

$$\text{where } \theta = \begin{cases} 90° - \tan^{-1}\left(\dfrac{\Delta N'}{\Delta E'}\right) & \text{for } \Delta E' > 0 \\ 270° - \tan^{-1}\left(\dfrac{\Delta N'}{\Delta E'}\right) & \text{for } \Delta E' < 0 \end{cases}$$

$$\Delta N' = D_N - C_N$$

$$\Delta E' = D_E - C_E$$

D_N - is the UTM northing displayed on the AN/ASN-128 when the aircraft was over the legs ending checkpoint position (B).

C_N - UTM northing displayed on the AN/ASN-128 when the aircraft was over the legs initial checkpoint position (A).

D_E - UTM easting displayed on the AN/ASN-128 when the aircraft was over the legs ending checkpoint position (B).

C_E - UTM easting displayed on the AN/ASN-128 when the aircraft was over the legs initial checkpoint position (A).

IEE - leg initial easting error of the AN/ASN-128 in meters.

$$IEE = C_E - A_E$$

INE - leg initial northing error of the AN/ASN-128 in meters.

$$INE = C_N - A_N$$

XTE - "cross track error" in meters.

$$XTE = DTD \times \sin (XT\angle E)$$

$$\text{where } DTD = (\Delta N'^2 + \Delta E'^2)^{-1/2}$$

ATE - "along track error" in meters.

$$ATE = DTD \cos (XT\angle E) - DT$$

RE - "radial position error" in meters.

$$RE = (\Delta EN^2 + \Delta EE^2)^{-1/2}$$

where $\Delta EN = D_N - INE - B_N$

$\Delta EE = D_E - IEE - B_E$

ΣRE - "total flight radial position error" in meters.

$$\Sigma RE = (\Delta EN'^2 + \Delta EE'^2)^{-1/2}$$

where

$\Delta EN' = D_N - B_N$

$\Delta EE' = D_E - B_E$

Calculation of the percent of distance traveled for any of the position accuracy parameters is as follows:

$$\%POS = \frac{POSE}{D_T} \times 100$$

where POSE is any position accuracy parameter.

For the total flight radial position error

DT = Accumulated distance flown.